INFORMATION PROCESSING OF DATA DESCRIBING ARBITRARY SOLIDS

SEMI-ANNUAL STATUS REPORT

December 1, 1966 - June 1, 1967

Herbert Freeman
Principal Investigator

July 1967

Sponsored by
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Prepared under
GRANT NGR-33-016-038

NEW YORK UNIVERSITY
SCHOOL of ENGINEERING and SCIENCE
DEPARTMENT of ELECTRICAL ENGINEERING
UNIVERSITY HEIGHTS BRONX, NEW YORK 10453

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ABSTRACT

This semi-annual status report summarizes the research work carried out during the period from December 1, 1966 to June 1, 1967 relating to the digital computer processing of data describing arbitrary solids. Three major investigations were carried out, consisting of (1) the contour map search problem, which was completed during this period, (2) the "hidden-line" problem for arbitrary polyhedra, and (3) the reconstruction of three-dimensional objects from two or more of their projections.

PERSONNEL

The following personnel contributed to the research described in this report:

Professor Herbert Freeman	Principal Investigator
Mr. Philippe Loutrel	Research Assistant
Mr. Stephen P. Morse	Research Assistant
Mr. Andrew Rabinowitz	Research Assistant

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INFORMATION PROCESSING OF DATA DESCRIBING ARBITRARY SOLIDS

I. INTRODUCTION

1.1 General

This semi-annual status report describes the research studies carried out in the Department of Electrical Engineering, New York University, during the period from December 1, 1966 to June 1, 1967, relating to the information processing of data describing arbitrary solids. The work was sponsored by the National Aeronautics and Space Administration under grant NGR-33-016-038 and completes the fourth half-year period of the program.

1.2 Statement of Objectives

The objectives of the research are to develop techniques for the analysis and manipulation of arbitrary three-dimensional geometric configurations by means of a digital computer. One problem of particular interest is that of obtaining perspective projections of solids illuminated by an arbitrarily located point source of light. The techniques (computer algorithms) to be developed are to facilitate the solution of this problem as well as generally to be of use for the solution of problems that involve the computer manipulation of data describing three-dimensional solids.

1.3 Investigations Undertaken

The research carried out during the past six-month period consisted of three specific investigations. The first of these was concerned with the topological and geometric properties of terrain contour maps, and with the solution of the so-called contour-map search problem. A solution to this problem was obtained, and the investigation was terminated with the publication of a doctoral dissertation. The second investigation had as its objective the development of an efficient algorithm for the solution of the "hidden-line" problem for polyhedra of arbitrary complexity. The third investigation was concerned with the reconstruction of an arbitrary polyhedron from two or more of its projections. Work on both of the latter two problems is to be continued during the coming period. All three investigations are briefly described in the following sections of this report. For details, the reader is referred to the reports and papers listed in the reference section.

II. THE CONTOUR-MAP SEARCH PROBLEM

As part of the research effort into the processing of data describing arbitrary solids, the solution of the so-called contour-map search problem was undertaken. In this problem an aircraft pilot is assumed to fly a path of known shape but unknown location or orientation over terrain for which a contour map is available. The pilot records the height of the terrain below the aircraft as a function of distance along his flight path, thereby obtaining a terrain altitude profile for the flight path. Upon return to base, the terrain altitude profile is entered in a computer together with the complete contour map data for the terrain. It is then the task of the computer to locate the flight path on the contour map in an efficient manner.

Most of the work on this problem was completed during the previous six-month period. Detailed descriptions have been included in previous status reports.[1-3] During the period covered by the present report, a comprehensive description of this problem was completed and published as part of a doctoral dissertation by S. Morse.[5] Also, a paper summarizing the solution of the contour-map search problem was published in a technical journal.[6] Two further technical papers have been written and submitted for publication.[7,8] Work on this problem is now considered completed and no further effort is planned.

III. THE HIDDEN-LINE PROBLEM

One of the primary objectives of the research carried out under this program is to find an efficient solution to the problem of determining the surface portions of an arbitrary three-dimensional object that are visible to an observer at a point p_1 when the object is illuminated from a source of light located at some point p_2, where the points p_1 and p_2 may be anywhere exterior to the object. With the restriction of considering only polyhedra, the problem reduces to the so-called "hidden-line" problem. This problem is the one of determining those edges or parts of edges of one or more polyhedra that are visible from an exterior observation point. If the polyhedra are illuminated from a point other than the observation point, one must determine those edges or parts of edges that are visible to both the observation point and the illumination point.

During the past six-month period, the algorithm for the solution of the hidden-line problem for non-convex polyhedra was completed. The basic approach is (1) to find all invisible edges and (2) to test the remaining potentially visible edges for either visibility, partial visibility, or invisibility. The concept of face extensions considered earlier was abandoned because of lack of generality and replaced by paths of potentially visible edges. Every potentially visible edge of the polyhedron is included in one and only one path. Consequently, if different paths exist for a given view of the polyhedron, these paths are necessarily disconnected. Equivalently, the only way to go from one path to another, is through invisible edges. The basic advantage of linking edges in paths is that the information obtained from the test of an edge can be used in the test of the next edge in the path. Finding and analyzing the properties of the origin vertex of a path is a major step of the algorithm. Once an origin vertex V has been located, all the edges radiating from V are tested for invisibility. Each of these potentially visible edges leads to a vertex V', which is tested. V' is then classified as either (1) an α-vertex, and all the potentially visible edges from V' are included in the path, or (2) a β-vertex and this branch of the path ends at V'. Sometimes isolated edges will be found, since a potentially visible edge between two β-vertices cannot be part of a path. This case, however, is exceptional, and the majority of the potentially visible edges will belong to some path. The test of an origin vertex is long and involves most of the potentially visible faces of the polyhedron. This is unavoidable, however, since, by definition, nothing is known a-priori about an origin vertex. The test of an α-vertex (or a β-vertex) is short and involves only the potentially visible faces that are issued from that vertex. This property is characteristic of a local test, and maximum use is made of this local test throughout the algorithm.

To date, the basic version of the algorithm has been programmed and tested. The program tests all potentially visible edges independently of each other. Equivalently, one vertex per edge is tested as an origin vertex. Several successful views of a non-convex polyhedron have already been obtained with this program (see Figure 1). A final version of the algorithm

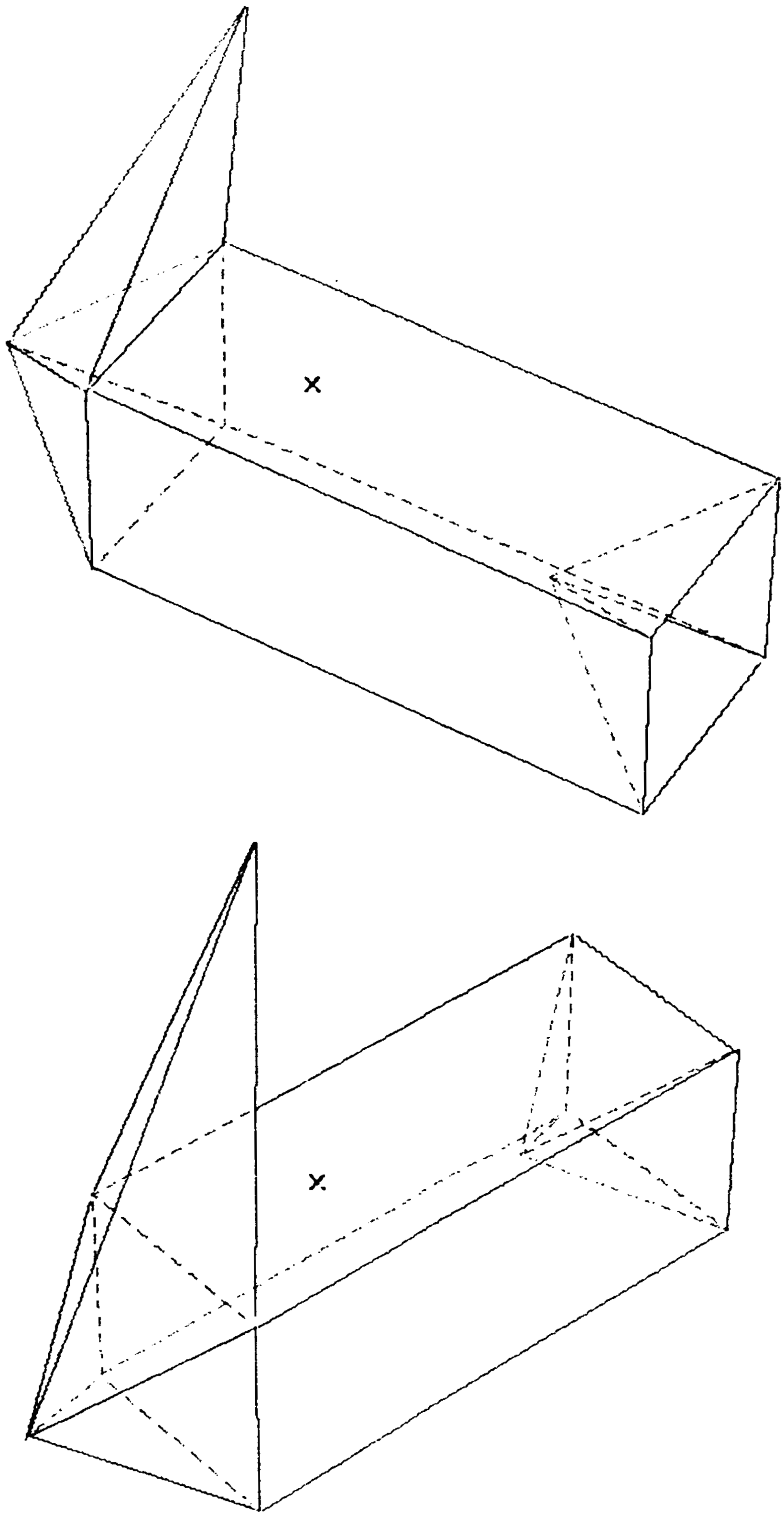

FIG. 1

ILLUSTRATION OF "HIDDEN-LINE" PROBLEM
(FIGURES WERE COMPUTED AND DRAWN BY COMPUTER)

has been programmed and is now being tested. The final version will include provision for determining the visible edges (and parts of edges) for polyhedra illuminated from a source of light located at a point other than that of the observer.

It is expected that work on the general hidden-line algorithm will be completed in the early fall of 1967. Preliminary results have already been published in a technical report.[9] A detailed description of the algorithm, together with a comprehensive analysis of the problem and actual computer-obtained results, is the subject of a doctoral dissertation currently in preparation.

IV. RECOGNITION OF 3D OBJECTS FROM THEIR PROJECTIONS

Work was continued during the past six months on the problem of determining to what degree it is possible to recognize a three-dimensional object from one or more of its perspective projections. This problem arises for example in connection with space exploration where a set of photographs of an unidentified object are obtained and it is desired to develop as complete a three-dimensional description of the object as possible. The solution of this problem requires the correlating and combining of different views of the object, and the interpolation and extrapolation of the information thus obtained to those parts of the surface for which no views are available. The extrapolation must be achieved using concepts of symmetry, similarity, balance and others that may be applicable.

To facilitate the solution of this problem, three restrictions have been imposed. These are: (1) only simply-connected polyhedra are considered, (2) it must be possible to arrange the projections in pairs such that the axes of projection in each pair are coplanar, and (3) the location of the centers of projection, and the orientation of the axes relative to each other must be known. A typical configuration is illustrated in Fig. 2.

The desired three-dimensional description of the polyhedra is obtained in three parts: (1) the portion of the polyhedra visible in two or more projections, (2) the portions visible in only one projection, and (3) the portions hidden in all projections. To obtain the first part it is necessary to determine the correspondence between the elements pictured in

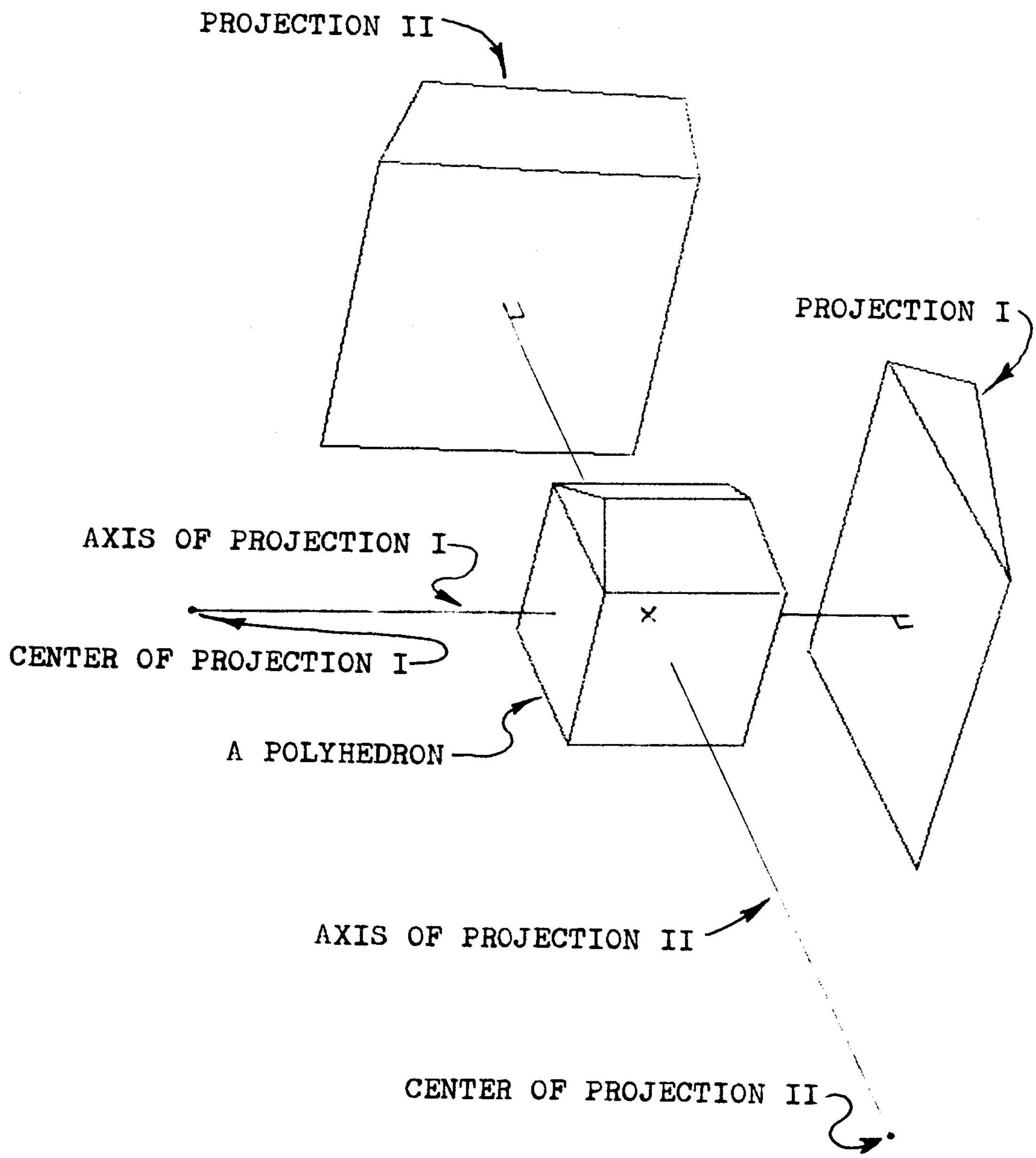

FIG. 2

ILLUSTRATION OF A POLYHEDRON WITH
TWO OF ITS PERSPECTIVE PROJECTIONS
(FIGURE DRAWN BY COMPUTER USING GRAPHPAK I)

each projection. For this purpose, the projected polyhedra vertices are grouped according to geometric constraints of the projection configuration as well as their forming edges and angle values. The second and third parts are constructed with the help of information obtained in the first, and with whatever assumptions that are necessary to fill in for any missing information.

Another feature of the approach to the problem is the division into subproblems. The criteria used for this purpose include: (1) orientation of axes - parallel, skew, or collinear, (2) number and type of polyhedra, (3) location of polyhedra relative to the centers of projection and, (4) relative positions of the polyhedra's projections in the picture planes.

The input data of the reconstruction algorithm consists of a vertex coordinate list, an incidence matrix, data describing the projection configuration, and a specification of the assumptions to be used (if any).

The algorithm is being coded in FORTRAN for an IBM 360 model 30 computer. To date subroutines have been written and tested for (1) arranging the vertices in groups representing potential faces and, (2) determining the face angles and edge lengths in the projections. A subroutine for matching vertices in two collinear type projections has been coded. Other parts of the algorithm for finding the vertex and edge correspondence, locating real polyhedra vertices and determining actual faces are partially developed. The work to date has been described in report[10] published during the past year and in a second report currently in preparation.[11]

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